J Musculoskel Interact 2000; 1:54-58

Original Article

Balance training and exercise in geriatric patients

M. Runge, G. Rehfeld, E. Resnicek

Aerpah-Klinik Esslingen, Germany

Abstract

Objective measures of gait and balance which meet the criteria of reliability and validity are required as a basis for exercise regimens. We established reference values of clinically relevant locomotor and balance performances for geriatric patients. We are using these data for evaluating the effects of different therapeutic approaches to locomotor and balance disorders. *Reference values for chair rising.* We administered a battery of five tests concerning neuromuscular function, locomotion and balance to a sample of 212 participants without apparent locomotor deficits (139 women, 73 men, mean age 70,5 years, SD 6,78 , median 70 years, range 60 to 90 years, recruited by public announcements). The test battery comprised the "chair rising test" for measuring lower extremity neuromusclar function (five repetitions of rising from a chair as quickly as possible with arms crossed over the chest). The test has been proven reliable, valid, sensible and predictive for falls and future locomotor status and ADL-status[2]. Chair rising [sec/5x], Range: 5.4-19.4, Mean: 9.1 (women:9.2, men:9.0), SD: 1.97, Median: 8.9. *Training of balance and muscle power with Galileo 2000 - preliminary results.* Galileo is a device for whole body vibration/oscillatory muscle stimulation. The subject stands with bended knees and hips on a rocking platform with a sagittal axle, which thrusts alternatively the right and left leg 7-14 mm upwards with a frequency of 27 Hz, thereby lengthening the extensor muscles of the lower extremities. The reflexive reaction of the neuromuscular system is a chain of rapid muscle contractions. We conducted a randomized controlled trial, n=34 (age: mean 67y, range 61-85, 11 female), cross-over design, intervention group 2 months training program three times a week (each session 3x2 minutes), performance tests of all participants every two weeks). The first 19 subjects have finished the intervention period. They reached mean performance gains in chair rising of 18 %, strikingly different to the constant values of the controls! We interpret the findings as improvements in muscle power by the oscillative muscle stimulation.

Keywords: Elderly, Fall, Fracture, Balance, Muscle Power

Geriatric medicine as medicine for the frail elderly focuses on functional independence and qualitiy of life. General objectives are treating diseases and preventing or minimizing disease-related and age-related functional decline and restitute functional independence after an acute illness.

What are the key factors of functional independence? There is an important observation about the gender differences in life expectancy and fitness in the aged. The higher life expectancy of women is well known. Controversely to the higher life expectancy the mean fitness level of female population is lower compared to male controls. In the Berlin Age Study the proportion of female participants who cannot independently manage a certain activity of daily living is consistently and significantly higher compared with males[1].

The lower proportion of functionally independent female elderly despite of their higher life expectancy is called the "gerontologic paradox". The factors which are responsible for the "gerontologic paradox" could also be general key factors for functional decline in the aged .

In the geriatric experience mobility is critical for functional independence and muscle function is critical for mobility. In the statistical analysis of the Berlin Age Study deficits of mobility/gait/balance have been found as the most important determinants of functional dependency, and muscle function of the lower extremities has been assessed as the single most important component for locomotor competence[2]. In most studies muscle function of the lower extremities has been measured as muscle strength, defined as maximal force that a muscle can produce against a given

Corresponding author: M. Runge, Aerpah-Klinik Esslingen, Kennenburger Str. 63, 73732 Esslingen. E-mail: RungeEsslingen@t-online.de

Accepted 23 February 2000

resistance. The presentations of H. Frost, H. Schiessl and J. Rittweger have demonstrated, that the term "strength" is not used very precisely in literature and medical practice. We should focus on muscle power, the product of force and speed and on the speed of force production. Whenever a muscle is moving a limb, it is generating power (the product of force and speed), and the speed of force development is perhaps critical for preventing stumbling becoming a fall. The force generated by muscles is strongly linked to the development of bone mass and bone strength as the Utah paradigm has taught us (cf. H. Frost; WSS Jee; JL Ferretti, H Schiessl). Muscle force is therefore linked both to bone strength and falling. Muscle function has been consistently found as a main risk factor for falls and hip fractures in the elderly.

The hip fracture incidence increases exponentially with age. More than 90 % of hip fractures result from a fall. We cannot understand the so-called "osteoporotic" hip fractures by discussing only the bone-related factors without regarding falls.

We have to discuss the conditions which predispose to falls, and consider the biomechanics of falling which generate the forces that break bones. Bones break because the forces applied to them exceed their strength. We have to consider the pathological cascade which leads from gait and balance disorder to fall and from fall to hip fracture[3] (Fig. 1).

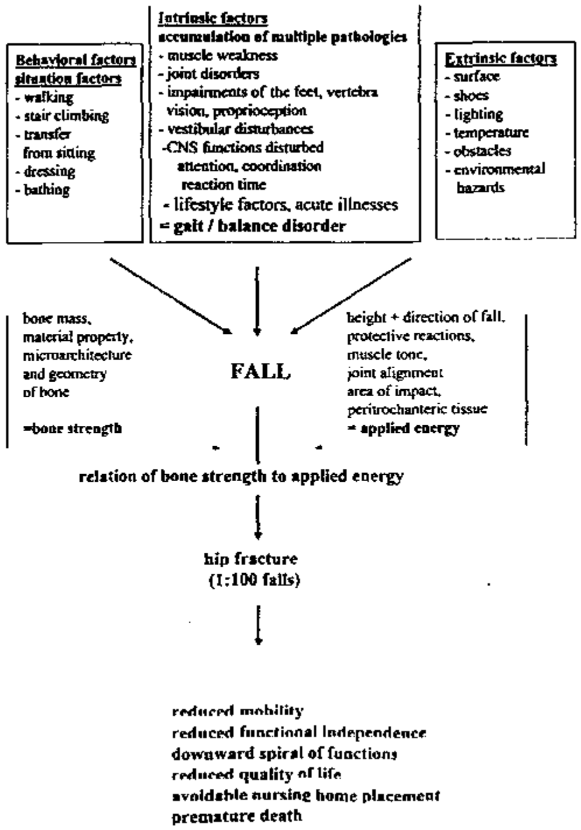


Figure 1. Pathogenic cascade "gait disorder, fall, hip fracture".

The energy generated by falling from standing position is far above the fracture threshold of elderly femurs[4,5]. The body falling from standing height has a velocity of about 2-4 m/sec. Data demonstrate that falling to the side and hitting the ground with the trochanter region has the strongest association to hip fracture[6].

Depending on body weight, height, joint alignment, direction of impact and protective reactions about 3500 – 12000 N are applied to a small area around the greater trochanter on a usual fall from a standing position. This fall-generated force of 3500 to 12000 Newton should not called a "minimal trauma" or "low energy trauma". The energy of such a fall is sufficient to break every femur of a person beyond 70 years of age, irrespective of osteoporosis[5,7,8]. Age alone decreases bone strength far below the fracture threshold compared with the force and energy generated by a fall from a standing position.

To understand the relationships between fall energy respectively peak force to bone strength we have to consider the active and passive protective mechanisms. Which mechanisms are responsible that only one of 100 falls results in a hip fracture? The passive protective mechanisms are the energy damping by the soft tissue around the greater trochanter (indicated by BMI) and the geometrical properties of the hip (hip axis length) and the whole body (The bigger they are the harder they fall). The peritrochanteric soft tissue can reduce the applied peak force by about 34 %[4]. The applied energy also depends on the joint alignment and the direction of the fall. Hitting the knee first protects against hip fracture, and changing the direction of the fall can also decrease the failure load by about 24 %[9]. Experimental findings and the decline of the incidence of distal forearm fractures with increasing age indicate a deterioration of active protective reactions with age.

Why do older people fall? 30 % of people 65 years of age and older fall each year, half of them more than once, and more than 50 % of nursing home residents fall each year (for details see Runge[10]). Five percent of falls result in a fracture, 1/5 of them hip fractures. Further 7 % of falls cause major injuries. Falls do not only break bones, they also break self-confidence. Because of fear of future falls patients restrict their physical activity, thus reducing also their social contacts. Older people blame themselves for falling and are afraid of overprotective behavior and nursing home placement by their proxys. More than 60 % of falls are not presented to others.

Falls in old age are not random events, or "accidents" caused by poor attention or external hazards. Falls in the aged can be foreseen, because they are mostly the result of a postural decline associated with certain age-related and disease-related conditions. By an appropriate examination we can diagnose the fall-risk-status and prescribe and apply effective therapies.

More than 90 % of falls happen in every-day situations as failure of locomotion without syncope, seizure or drop attack. Mostly multiple subsystems of the postural system are compromised. The postural competence (=balance) of the fallers is very near to the threshold of locomotor failure during usual daily tasks, and as time goes by falls will happen. A fall assessment must differentiate between syncopal and nonsyncopal falls.

Apparently these two groups differ completely in pathogenesis and require a different approach. It is a consistent result of prospective studies that 90 %-95% of falls are not caused by loss of consciousness or loss of muscle tone. Syncope, seizures, vertigo/dizziness or drop attacks are responsible for only 5 % of falls in prospective studies. But these syncopal falls are seen as medical problems compared with locomotor falls, and are presented to doctors, however the (nonsyncopal) locomotor falls are considered as accidents without the chance of medical treatment. This is a fatal misunderstanding preventing medical diagnosis and therapy of fall-status.

The percentage of falls caused by overwhelming external forces is not greater than 5 % [11-15].

Consistent findings of prospective fall and fracture studies are:

- The individual fall-risk status is mainly determined by the number of intrinsic predisposing factors. The more risk factors the more falls (Fig. 2 and 3).
- Fall risk factors can be identified by appropriate examination. The individual likelihood of future falls can be predicted by the individual risk factor profile.
- Most falls happen during common daily locomotor tasks without extraordinary challenge of the postural system.
- About 12 % of falls result in major injuries, 5 % of all falls result in fractures, 1 % in hip fractures.
- Hip fractures are the most devastating in respect to death, dependency and functional decline.

We have to differentiate between risk factors for locomotor falls generally, for injurious falls and risk factors for different types of fractures. Etiology and pathogenesis are very different related to different fracture types, especially falls are far more important for hip fractures than for vertebral fractures. Which risk factors should be treated? There are hundreds of parameters which have been found associated with increased fall risk. There is no single study that has found the same set of risk factors (Fig. 2,3). The key question is: Which factors have been found to be independently (!) associated with fall risk?

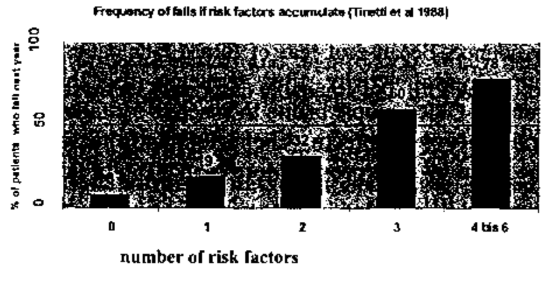
The clinically most important and consistently found fall risk factors are:

- impaired muscle strength/muscle power of lower extremitites
- impaired balance/postural control
- impaired gait (clinically assessed)
- impaired vision
- fall-associated medications/number of medications
- impaired cognitive functions

Age, race, gender and body habitus are all associated with fall risk respectively hip fracture risk but cannot be treated. General indicators of fall risk are habitual physical inactivity, functional deficits in activities of daily living, use of assistive devices during locomotion, and a history of recurrent falls, especially falls with injuries or falls with resulting inability to get up without help.

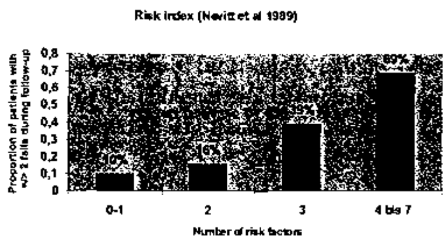
Figure 1 presents our concept of the pathological cascade which leads from gait and balance disorders to fall and to hip fracture. The relationships between gait and balance disorders and fall risk are multifactorial and non-linear, and so are the relations between biomechanics of a fall and fracture. Data give strong evidence that monocausal explanations of falling of the aged are not appropriate. For 100 falls we can find 300-400 causes. The traditional approach to explain adverse health events by diagnoses respectively single diseases is not appropriate related to falls.

Analysing the fall situation we have to differentiate three sets of factors: the postural competence of the individual, the activity in the moment of fall, the physical environment. Two critical relations determine the failure of locomotion and the



Independent risk factors for falls
- Use of sedatives
- Cognitive impairment
- Lower extremity disability
- Palmomental reflex
- Balance-and-gait abnormalities
- Foot problems

Figure 2. Independent risk factors for falls in the next year [12].



Independent risk factors for 2 falls or more in the follow-up year
- Difficulty standing up from chair (unable or > 2 sec)
- Poor tandem gait
- History of arthritis
- Diagnosis of Parkinson's disease
- 3 or more falls in previous year
- Previous fall with injury
- White

Figure 3. Risk factors for Recurrent Nonsyncopal Falls [14,17].

outcome of a fall (Fig. 1): 1) the relation between postural control and postural demands, 2) the relation between applied forces and bone strength.

We have to focus on these relationships in order to understand and prevent hip fractures. Focussing on bone alone addresses only part of the problem. It is the combination of both age-related propensity to fall and reduced bone strength that lead to the steep increase in hip fracture incidence.

Both factors are strongly related to muscle function. Therefore it seems promising to focus on treatment of muscle mass and function. Muscle function respectively muscle force is related both to fall propensity and bone strength. Perhaps the speed of force development is the point to prevent that stumbling results in a fall and that a fall results in an impact on the trochanteric region.

Preventing a fall requires quick neuromuscular reactions exactly adapted to perturbations of balance. Preventing that a fall results in a hip fracture requires quick protective reactions in order to prevent an impact at the trochanteric region. Therefore we have to look for a clinical test to measure muscle power of the lower extremitities. According to this concept poor performances in the chair rising test has been proven reliable, valid and predictive of future falls, hip fractures, functional decline, nursing home placement and premature death[2,16]

Chair rising test

The subject has to rise from a usual chair (46 cm height) five times as quick as possible without using one's arms. The Table 1 shows reference values of a cohort of fit elderly volunteers without reported or apparent disease or disability relating to locomotor performances (n=212, mean age 70 yr, range 60-90 yr, recruited by public announcement). Establishing reference values of locomotor perfomances is part of the PISA-project (PISA = Parameter für Instabilität und Stürze im Alter).

The values of the chair rising test represent muscle power, because the participants perform a certain work (lifting their own body) in the measured time (power equals work per time).

Range [sec]	Mean [sec]	SD [sec]	Median [sec]
5,4 – 19,4	9,1 (w 9,2; m 9,0)	1,97	8,9

Table 1: Chair rising 5x without using one's arms, w=women, m=men, n=213 (60-90 yr).

Training of balance and muscle power with Galileo 2000

We have used the chair rising test to study the effects of a new training device (Galileo 2000, Novotec Pforzheim Germany). Galileo 2000 is a device for applying "whole body vibrations" ("oscillatory muscle stimulation" , reflex muscle stimulation). The subject stands with bended knees and hips on a rocking platform with a sagittal axle, which thrusts alternatively the right and left leg 7-14 mm upwards with a frequency of 27 Hz, thereby lengthening the extensor muscles of the lower extremities and generating rapid muscle contractions as reflex actions of the neuromuscular system.

Since six months we use the Galileo 2000 in the rehabilitation routine of our geriatric clinic (167 beds, about 2000 in-patients a year). We apply the "reflex muscle stimulation" in order to improve balance and muscle power. We have established a standardized protocol for the observation of adverse side effects. We rely heavily on the patient reports and monitor the musculoskeletal and cardiovascular system. We exclude patients with acute lesions and disorders of the spine and the lower extremities, acute arthritis, acute urolithiasis/cholelithiasis, acute thrombosis. We have not observed any serious side effect.

We conducted a randomized controlled study with 39 participants, mean age 67 yr (range 61-85 yr). We recruited the cohort by public announcement looking for subjects without any indicator of reduced mobility. We wanted to compare the effects of therapy upon a stable locomotor condition. Thirty four participants finished the 4 months of

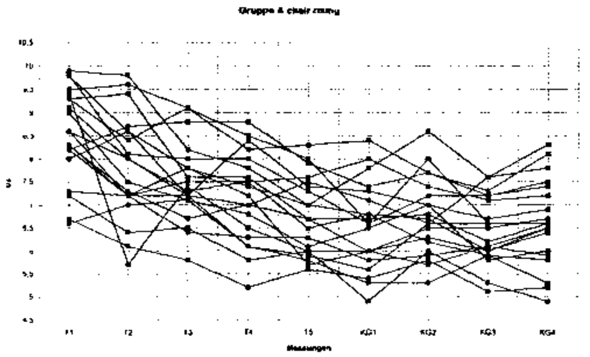


Figure 4. T1-T5 are the time points of the fortnightly chair rising tests of the intervention period, KG1-KG4 are the time points of the tests during the control period.

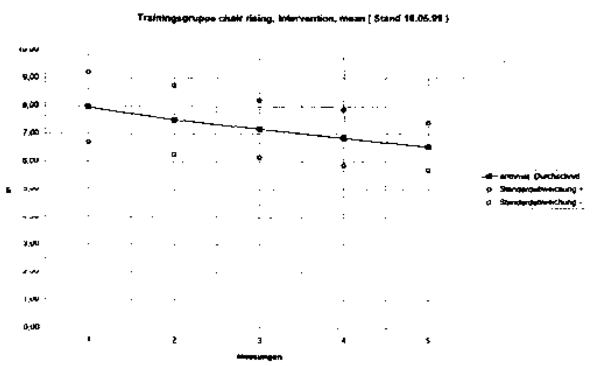


Figure 5. Improvement of chair rising test during the intervention period, mean ±SD.

the study, 5 participants dropped out. The test protocol comprised a standardized interview about possible side effects. Apart from one mild inflammation of the forefoot which was perhaps partially related to the training we observed no adverse side effects. The other causes for dropping out were not related to the training.

We used a cross-over design, each participant had to carry through an intervention period of two months and a controll period of two months. The intervention group attended the 2-months training program three times a week (each training session on the Galileo 3x2 minutes), both the intervention group and the control group were applied performance tests every two weeks. This group of fit elderly participants reached a highly significant mean increase of chair rising time of 18 %, whereas the values in the control group showed no significant difference.

Thirty three of 34 participants improved their chair rising time in the intervention period up to 36 % (Fig. 4,5). We interpret the findings as improvements in muscle power resulting from the reflex muscle stimulation with the Galileo 2000. We intend to continue studying this new training device with improved diagnostic methods, measuring power output of the sit-to-stand movement by a specially designed force plate.

References

1. Steinhagen-Thiessen E, Borchelt M. Morbidität, Medikation und Funktionalität im Alter in: Mayer K, Baltes PB (Hrsg): Die Berliner Altersstudie. Akademie Verlag Berlin 1996; 151-183.
2. Guralnik JM, L Ferrucci, EM Simonsick, ME Salive, RB Wallace. Lower-Extremity Function in Persons Over the Age of 70 Years as a Predictor of Subsequent Disability. N Engl J Med 1995; 332:556-61.
3. Runge M. Die multifaktorielle Genese von Gehstörungen, Stürzen und Hüftfrakturen im Alter. Z Gerontol Geriat 1997; 30:267-275.
4. Robinovitch SN, Hayes WC, McMahon TA. Prediction of femoral impact forces in falls on the hip. J Biomech Eng 1991; 113:366-374.
5. Courtney AC, Wachtel EF, Myers ER, Hayes WC. Age-Related Reductions in the Strength of the Femur Tested in a Fall-Loading Configuration. J Bone Joint Surg 1995; 77:387-395.
6. Hayes WC, Myers ER, Morris JN, Gerhart TN, Yett HS, Lipsitz LA. Impact near the hip dominates fracture risk in elderly nursing home residents who fall. Calcif Tissue Int 1993; 52:192-8.
7. Hayes WC, Myers ER, Robinovitch SN, van den Kroonenberg A, Courtney Ac, McMahon TA. Etiology and prevention of age-related hip fractures. Bone 1996; 18:77S-86S.
8. Greenspan SL, Myers ER, Maitland LA, Resnick NM, Hayes WC. Fall Severity and Bone Mineral Densitiy as Risk Factors for Hip Fracture in Ambulatory Elderly. JAMA 1994; 271:128-133.
9. Pinilla TP, Boardman KC, Bouxsein ML, Myers ER, Hayes WC. Impact Direction from a Fall Influences the Failure Load of the Proximal Femur as much as Age-Related Bone Loss. Calcif Tissue Int 1996; 58:231-235.
10. Runge M. Gehstörungen, Stürze, Hüftfrakturen. Steinkopff-Verlag Darmstadt 1998.
11. Tinetti ME, Williams TF, Mayewski R. Fall risk index for elderly patients based on number of chronic disabilities. Am J Med 1986; 80:429-34.
12. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N Engl J Med 1988; 319: 1701-1707.
13. Robbins AS, Rubenstein LZ, Josephson KR, Schulman BL, Osterweil D, Fine G. Predictors of falls among elderly people. Results of two population-based studies. Arch Intern Med 1989; 149:1628-33.
14. Nevitt MC, Cummings SR, Kidd S, Black D. Risk factors for recurrent nonsyncopal falls: a prospective study. JAMA 1989; 261:2663-8.
15. Campbell AJ, Borrie MJ, Spears GF. Risk factors for falls in a community-based prospective study of people 70 years and older. J Gerontol 1989; 44:M112-17.
16. Cummings SR, Nevitt MC, Browner WS, Stone K, Fox KM, Ensrud KE, Cauley J, Black D, Vogt TM, for the Study of Osteoporotic Fractures Research Group. Risk factors for hip fracture in white women. N Engl J Med 1995; 332:767-73.
17. Nevitt MC, Cummings SR, Hudes ES. Risk Factors for Injurious Falls: A Prospective Study. J Gerontol 1991; 46: M164 - M170.